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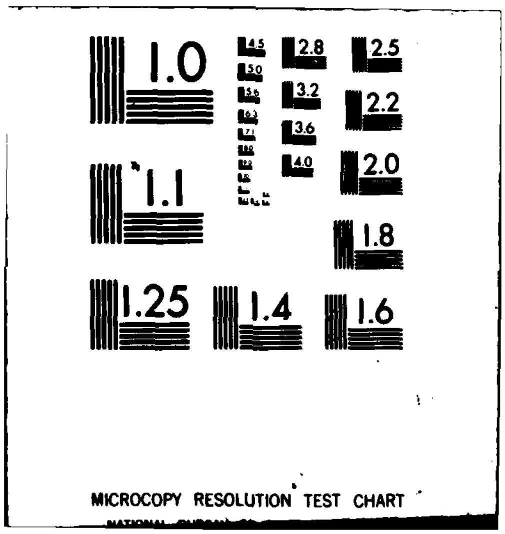
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LASER OCULAR FLASH EFFECTS (U)

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INTRODUCTION

During this decade, lasers on the modern battlefield will become a directed energy threat to the eyes of ground force military personnel(1,2,3). One needs only to reflect on the enormous increase in electro-optical battlefield devices presently being developed to both train and equip troops for combat to suspect that a dramatic increase in accidental and intentional exposure incidence may well occur. Laser rangefinders (single pulse) and designators (multiple pulse) are anticipated to be commonplace in the modern electronic battlefield. While the future may hold to the concept of a laser injury as radiation that "vaporizes" its target, now we need only to be concerned with those devices that disrupt the complex man-machine interface by ocular injury. Such interfaces are critical to a modern equipped Army, and ocular injury will severely affect this complexity. Laser devices that inflict such ocular damage are easily available and will be prolific in ground battlefield scenarios. The present investigation was designed to incorporate several key features of the military scenario in order to address the question of a low level laser threat to the eye and acute vision.

To understand the nature of the low level laser threat, we need to understand some critical aspects of ocular anatomy, vision, and the nature of a laser exposure made under field conditions. The retina is the sensory tissue that is responsible for transducing light into simple visual sensation. Such sensations, processed as electrical impulses both within the retina and in the visual brain centers, produce our most complex visual experience. If a portion of this tissue is destroyed, vision can be permanently or temporarily altered. The photoreceptors, the actual biological transducers of light impulses into electrical impulses, are not uniformly distributed. The cone photoreceptors, concentrated in the fovea, are responsible for acute vision, maximal visual acuity, and fine spatial

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vision. If the fovea is damaged, visual acuity is dramatically altered and the visual scene is blurred. The fovea, a relatively small piece of the human sensory retina, is at the center of the optical axis of the eye. Thus, use of military optics places the fovea in a most vulnerable position.

In several previous experiments we demonstrated that foveal laser exposure could dramatically alter the ability to resolve fine spatial detail, i.e. visual acuity (4,5). These experiments demonstrated both permanent, as well as transient changes in acuity associated with moderate to low levels of laser flash exposure. But all of these previous experiments were done with relatively large retinal spot sizes (150-350 microns). In the field, however, the laser flash will produce a small retinal spot (30-50 microns) because of the laser's low divergence. Our questions in the present experiment were: will such exposure produce a significant effect on the retina and visual acuity? Will small punctate foveal exposures have an effect on visual acuity similar to that of larger retinal spot exposures, where the entire fovea was involved? Will small spot foveal exposure affect retinal areas outside the fovea?

By measuring contrast sensitivity across a range of acuity target sizes, we were able to assess the possible lateral influence of small spot laser flash exposure. While visual acuity expresses the very finest target that can be resolved spatially, it does not reflect spatial visual function for larger targets. In order to measure the effects on liminal spatial vision for large as well as small targets we measured contrast thresholds as well as visual acuity. The reciprocal of the minimum contrast ratio threshold is contrast sensitivity, and one may plot a function relating contrast sensitivity to acuity target size or spatial frequency. In the contrast sensitivity function the smallest resolveable target has the lowest contrast sensitivity, requiring the highest contrast threshold.

In this experiment we have not only simulated battlefield exposures with small retinal spot exposure but, because many field laser systems are repetitively pulsed, we have also employed a repetitively pulsed laser system. The wavelength of the laser source (532nm) is close to the peak of the daytime maximum color sensitivity of the human and monkey eye (550nm).

METHODS

Rhesus monkeys were trained on a visual acuity task in which exposure to a laser flash could be administered during task performance (4,5,6). Animals were trained for many months to discriminate bright achromatic Landolt ring acuity targets, rings with gaps ("C's"), from other bright ring targets that lack this gap ("O's"). The minimum resolveable spatial detail (visual angle) for the rhesus monkey is similar to that of the human.

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The rhesus is also quite comparable to the human in its minimum contrast threshold for various target sizes. To measure contrast sensitivity, the gap of the Landolt ring was expressed as an aperiodic spatial frequency.

In order to expose an animal and track the immediate visual consequence of a laser exposure in a reliable manner for at least a half hour post-exposure, very stable visual function baselines were required. Spatial vision thresholds (visual acuity and contrast sensitivity) were determined by a method that allows instantaneous determination of threshold (7). The rhesus were trained to titrate either the size or the contrast of the acuity targets about their threshold. Following initial discrimination learning and determination of acuity or contrast sensitivity for a given acuity target, animals were trained to yield highly stable baselines with minimum variation over a period of at least an hour. Stability criteria of approximately 0.2 to 0.4 log units in either acuity or contrast sensitivity maintained over a 30 to 60 minute period were generally required before any animal was considered ready for exposure.

For two animals trained to track only their high contrast acuity, three to four exposure sessions were given to establish reliability of a given exposure level. Exposure levels were increased until a criterion deficit of about 90 % of baseline acuity could be obtained for about 2 minutes post-exposure. For three contrast sensitivity animals, the effect of laser flash exposure was determined on one spatial frequency at a time for three to four exposure sessions.

Laser flash effects were obtained for small spot pulsed visible laser (532 nm) flash exposure on visual acuity, and contrast thresholds for spatial frequencies from 38.5 cycles/degree to 2.2 cycles/degree, (i.e. Snellen acuity notation from 20/15 to 20/267). All exposures were made with the flash presented through the gap in a .78 minute of arc (20/15) Landolt ring. This assured foveal exposures, as the fovea was required for accurate discrimination of this size target. An exposure was made if the daily pre-exposure baseline was within 0.4 log units of the previous session's baseline for acuity or constrast sensitivity. A frequency doubled Neodymium laser (532 nm) operating at 20 Hz was used. Exposure consisted of six 20 nsec pulses delivered within a 300 msec time window. In the early portions of this experiment a 10 Hz pulse repetition frequency (PRF) was employed and six pulses were cumulated over three successive trials spanning a period of 36 seconds. The average calculated nominal Total Intraocular Energy (TIE) per pulse was 3.0 uJoules for a 5 mm pupil in high contrast acuity recovery tests. All contrast threshold functions were measured against a 70 ft L. background and, therefore, a 3 mm pupil was assumed for calculation of the total intraocular energy (1.1 uJoules). All TIE levels are nominal values with variation of TIE about ± 20% within a given animal.

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Five animals were used in these experiments. All had pretraining refractive errors of less than a 1/2 diopter; all had normal appearing fundi prior to exposure. Fundi of selected animals were reexamined only after an entire exposure series for the given animal was complete.

RESULTS

An acuity threshold session, lasting about 60 minutes, from one animal is presented in Figure 1. Landolt rings presented to this animal immediately after exposure had to be increased in size to a Snellen acuity level of 20/108 before tracking of post-exposure recovery could be

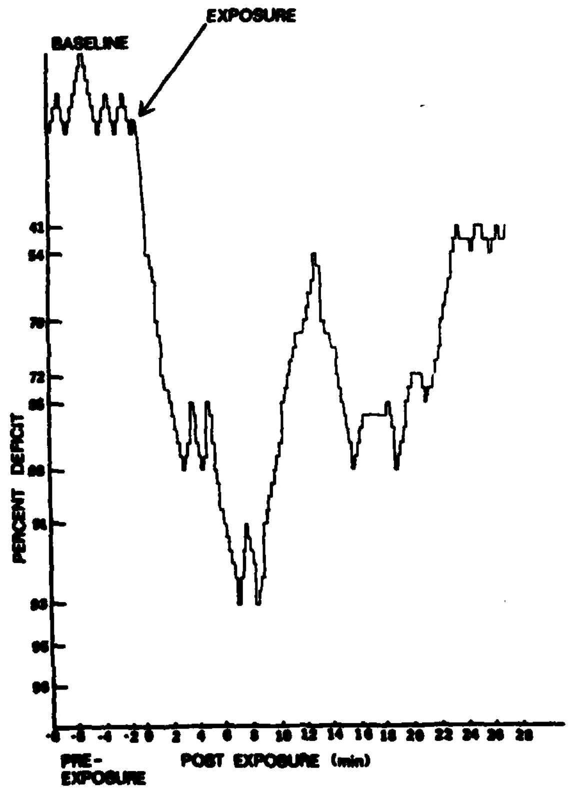

Figure 1. Raw data taken from an acuity exposure session is shown. The Y-axis is an ordinal scale where the location of Landolt rings in a size graded series of acuity targets is expressed as a percent deficit relative to the pre-exposure baseline. The last 8 minutes of the pre-exposure acuity baseline is followed by a laser exposure. A maximum acuity deficit of approximately 93% was seen as long as 8 minutes post-exposure. At 28 minutes, recovery was to about 50%, with full recovery occurring within 1 hour post-exposure.

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achieved. This post-exposure threshold acuity level corresponded to at least a 90% deficit with respect to pre-exposure acuity baseline, and was persistent for several minutes post-exposure. Even after recovery began, it was slow and incomplete at the end of 30 minutes. At the end of the actual 50 minute post- exposure session, however, the animal's acuity baseline had returned to pre-exposure levels. No subsequent deficit was noted on successive test sessions.

In Figure 2, recovery curves for visual acuity (2a) and contrast sensitivity (2b) are presented. Two acuity recovery functions are shown in 2a. Both of these functions were obtained in a manner similar to that shown in Figure 1, except here we have averaged the acuity for each two minute block of post-exposure data over several exposure sessions for one animal. The lower curve was obtained from exposure to 6 pulses at a 10 Hz pulse repetition frequency, while the upper curve was obtained from exposure to 6 pulses at a 20 Hz pulse repetition frequency. In the former,

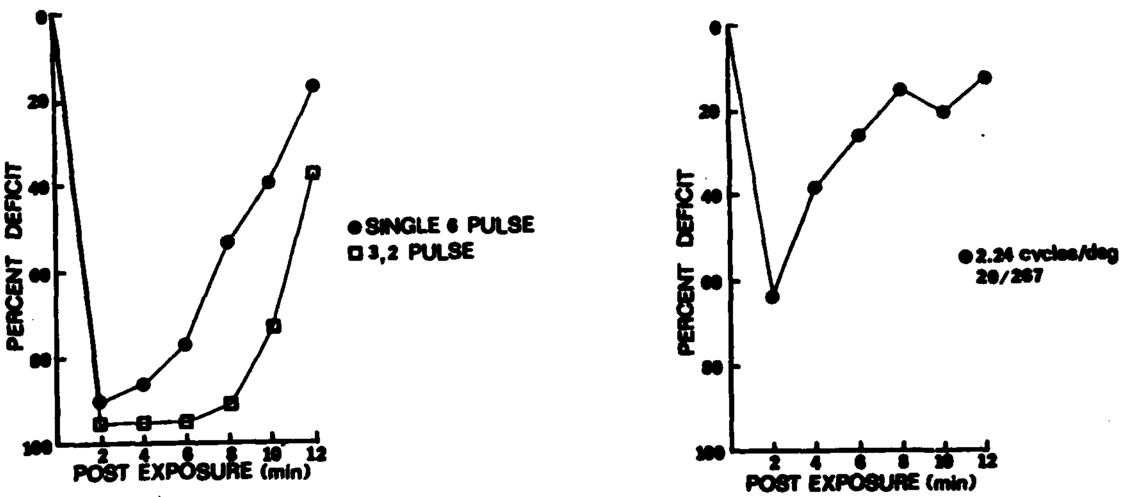

Figure 2. Post-exposure recovery curves for acuity (2a) and contrast sensitivity (2b) are presented as percent deficit relative to pre-exposure baselines. Significant initial deficits and recovery from such deficits are represented. The recovery curve for contrast sensitivity (2b) was measured with a large target having a spatial frequency of 2.24 cycles/degree. The acuity recovery curves represent the average of 4 exposure sessions for each condition, while the contrast sensitivity recovery curve is an average of 20 exposure sessions across 3 animals. By inspection, these average curves are highly representative of all individual recovery functions.

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six pulses were delivered in 2 pulse bursts on three consecutive Landolt ring trials over a 36 second period, whereas in the latter curve the 6 pulses were delivered in a 300 msec interval on a single Landolt ring trial. While a more prolonged recovery time is evident for the 10 Hz repeated trial exposure, both require close to 20 minutes for full recovery to occur.

Figure 2b is a recovery function of the contrast sensitivity for an acuity target equivalent to 20/267 Snellen, or a spatial frequency of 2.2 cycles/degree. It is a large target that involves foveal as well as parafoveal stimulation. Initial deficits in contrast sensitivity, and recovery times for such size targets were essentially the same as those for targets requiring much smaller foveal areas. Similar curves for 20/15 Snellen acuity targets, or spatial frequencies of 38.5 cycles/degree, were essentially equivalent in the time course of recovery. Both small and large targets showed little recovery during the first two to four minutes post-exposure. After the initial four minutes post-exposure, full recovery required about 15 minutes. Post-exposure contrast threshold 95% confidence limits did not overlap those of baseline in any specific animal until about 6 minutes post-exposure. Statistical significance of post-exposure relative to pre-exposure thresholds for $p<.05$ was obtained during the first 4 to 6 minutes in all animals. Recovery became more variable both within and across animals beyond 6 minutes post-exposure.

Although an immediate and substantial deficit in spatial vision was usually produced, not every exposure produced the same initial loss. The histograms of Figure 3 show the percentages of exposure trials required to produce criterion deficits of 40, 60, or 70 % within the first 2 min post-exposure. Data were taken from three contrast sensitivity animals from all exposures where 38.5, 10.0, and 2.24 cycles/degree were used as test spatial frequencies. A total of 92 exposure sessions are represented.

Most exposure sessions produced a 40% deficit over the first 2 min of exposure regardless of spatial frequency. About 90% of all exposures tabulated produced a deficit >40% for these initial 2 min post-exposure; about 60% of all exposures produced deficits >60%; and, between 35 and 60% produced deficits >70%. In all three categories, the largest spatial frequency was affected at least to the same degree as was the finest spatial frequency. The intermediate spatial frequency seemed somewhat less affected than those at the spatial frequency extremes. When the complete spatial frequency spectrum is plotted, it is evident that intermediate spatial frequencies were somewhat less affected initially and recovered more rapidly than either the largest or the finest spatial frequencies.

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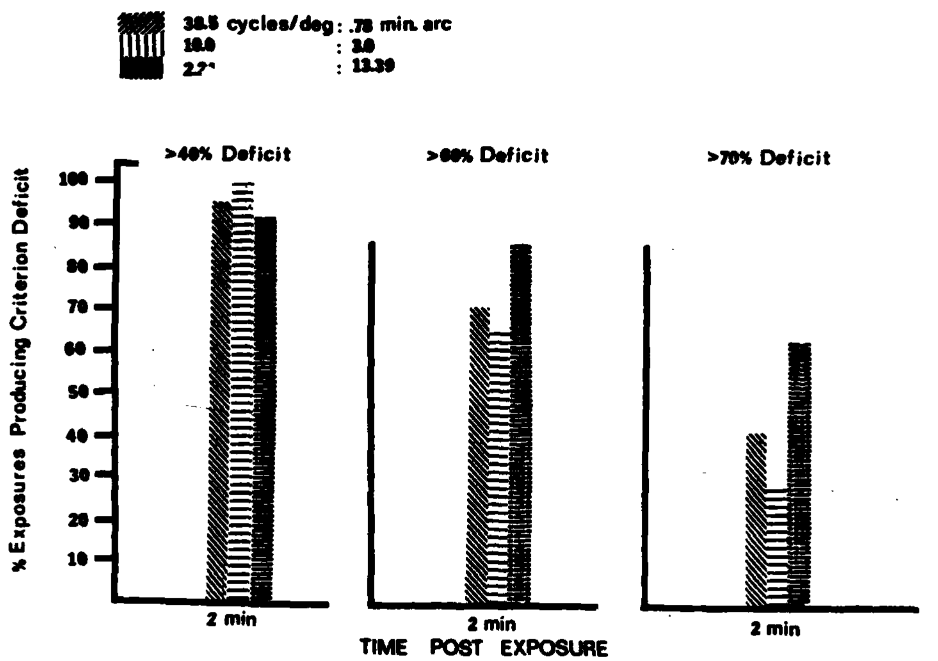

Figure 3. The degree of maximum deficit in contrast sensitivity was not uniform for all exposures. Variability can be seen in the amount of post-exposure change, with less than 50% of the exposures resulting in deficits greater than 70% of baseline levels, while deficits greater than 40% were produced on more than 90% of all exposures. Deficits greater than 60% were produced on 60-80% of the exposures. These data represent a total of 92 exposure sessions across 3 animals.

Several exposure sessions produced deficits in either acuity or contrast sensitivity that lasted more than the duration of the test session, and appeared more selective to the highest spatial frequencies. Such effects, however, were difficult to quantify fully because of their infrequence in the present study. However, recovery from these exposures always occurred with several post-exposure sessions.

Fundus observations of animals examined after the completion of all laser exposure sessions revealed small punctate lesions in the foveal areas including the foveola, the central portion of the fovea. A fundus photograph taken from one of the subjects is shown in Figure 4.

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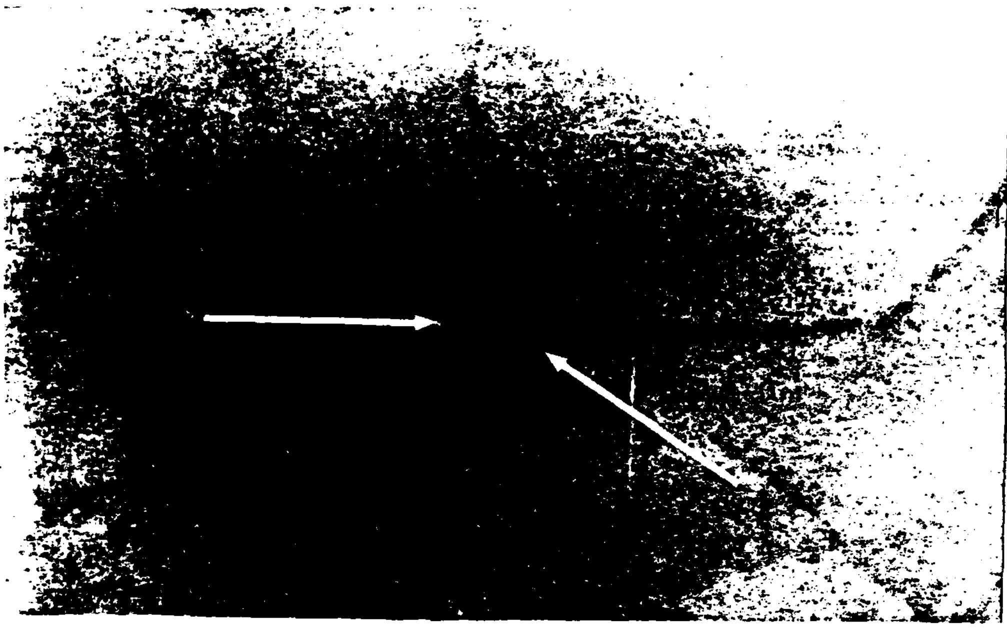

Figure 4. Rhesus fundus showing "punctate" foveal lesions. Arrows indicate the location of the lesions.

DISCUSSION

We have demonstrated that small spot laser flash exposures produce transient changes in high contrast visual acuity and contrast sensitivity These data indicate that effects may involve areas greater than the predicted retinal image diameter of 30 to 50 microns.

Several possible explanations are applicable to these findings. Most exposures in this experiment involved trains of Q-switched pulses. Such exposure conditions in combination with small eye movements may have "painted " a larger effective retinal spot across the fovea than would have been possible with a single pulse alone. In our early experiments, we used a 10 Hz PRF, and distributed six pulses over a 36 second period, 2 pulses per trial. This exposure condition (Figure 2a-lower curve) produced a longer lasting initial deficit than a single burst of six pulses delivered over 300 milliseconds.

As most exposures made were at the ED_{50} for retinal burn criterion, a second factor, local retinal edema, is possible as well. Local edema and its spread to neighboring retinal areas might well have affected parafoveal areas for a short period of time. Such a phenomenon was suggested to explain analogous effects for total foveal damage (4).

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Neural retinal interactions are a third element in the explanation of these effects. The visual fields of foveal photoreceptor neural systems (foveal receptive fields) typically are considered to be small, subserving a small number of photoreceptors located within the fovea. While these results do not comment on the size of foveal receptive fields directly, they suggest that foveal receptive fields may overlap parafoveal areas, so that a foveal alteration could affect parafoveal processing of photoreceptor input.

In addition to producing large changes in fine spatial vision, these flashes frequently produced initial delays in the recovery function. Such delays were generally evident during the first 2 to 4 minutes following flash exposure. A similar finding has been reported for longer pulse widths (100 msec) and larger retinal spot sizes (150 to 350 microns) (5). Such delays in recovery after flash increased with exposure power up to permanent acuity losses. Temporary delays in recovery may be reflective of foveal neural "inelasticity" or foveal "blanking" as well as local retinal edematous changes.

Permanent changes lasting more than a single session were not as evident as those obtained in previous work, where large spot-induced foveal damage produced long-term loss in visual acuity that required at least six months for recovery, and longer term residual loss in color vision (4,8). In the present experiment, while portions of the fovea may be damaged, the long term effects are either non-existent or difficult to measure, perhaps requiring more sensitive spectral measurement(4,8). Nevertheless, obvious lesions were produced in and around the fovea. The possibilities that foveal receptive fields are larger or more dynamic than originally conceived (9,10) or normal foveal function can be maintained by the "spared" foveal areas are suggested as explanatory factors.

These results have significant implications for lasers on the modern battlefield. We have shown that minimal spot laser exposure can affect liminal spatial visual function, as well as foveal retinal tissue. Tactically, a compromise in the ability to resolve fine spatial detail in low contrast ground environments may produce an immediate field casualty. Subtle changes in lighting conditions as occur at dawn or dusk, in target reflections and glare, contribute to altering subtle contrast and fine spatial detail required in any complex target acquisition task. Under such conditions, a small induced change in minimal spatial resolution threshold or contrast threshold could result in failure to acquire a critical target. On the other hand , many military scenarios require acquisition of high contrast targets where the requirement for the resolution of fine spatial detail is less stringent. Such situations could be affected to a lesser degree by point source flashes(11), although alteration of retinal foveal tissue is still as likely as in the above military scenario.

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We have shown that laser flash exposure can produce significant changes in fine spatial vision and that such effects can be produced with small spot retinal flashes that are likely from highly collimated fielded laser systems. These effects may produce injury to the retina as well as transient loss in fine spatial detail and alteration of normal contrast requirements for optimal target acquisition functions. Such transient effects may, therefore, interfere with mission completion as well as having unknown long term consequences for normal foveal vision. These effects represent a potentially serious Army field hazard regarding both present and near term development of Army laser systems.

In conducting this research, the investigators adhered to the "Guide for Laboratory Animal Facilities and Care", as promulgated by the Committee on the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Academy of Sciences- National Research Council.

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